Deep space observations of oriented ice crystals

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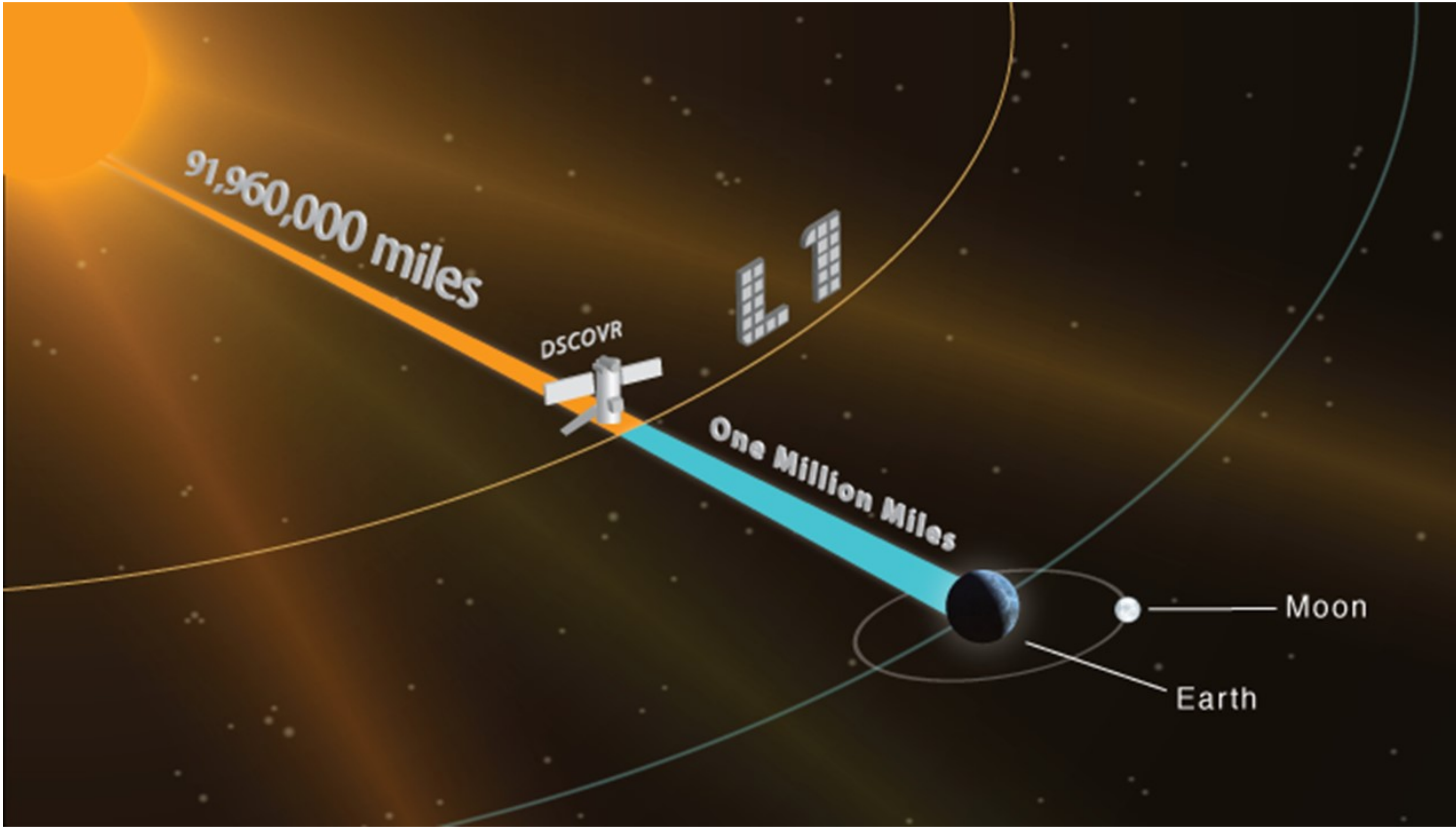
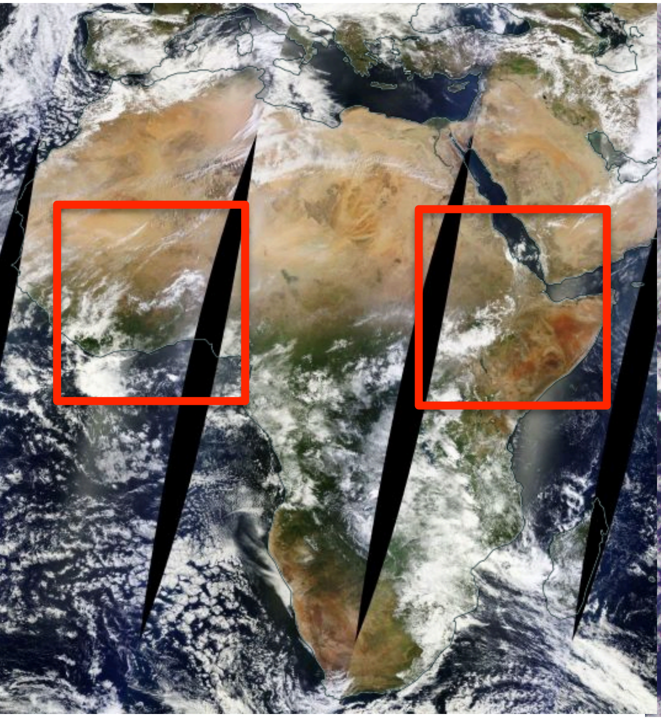
The Galileo mission and its near L1 earth images

Suggestion by Sagan et al. (1993, *Nature "A search for life on Earth from the Galileo spacecraft")*

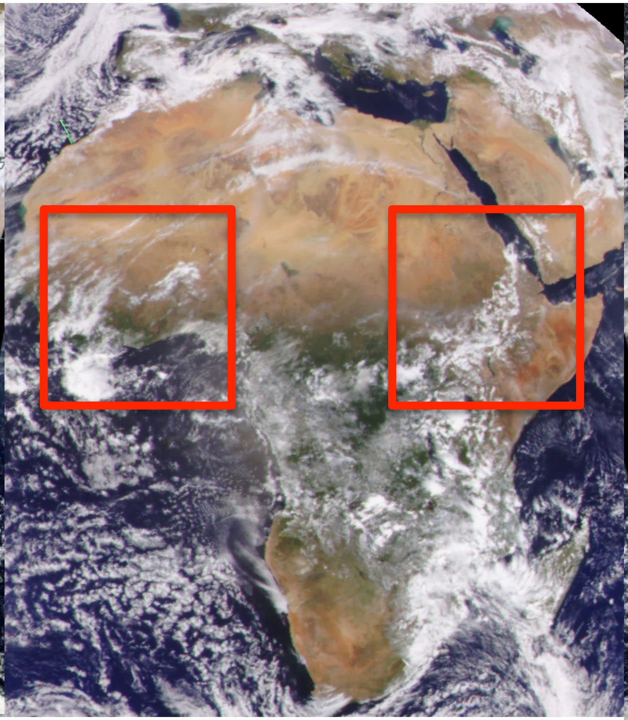
DSCOVR at Lagrange-1



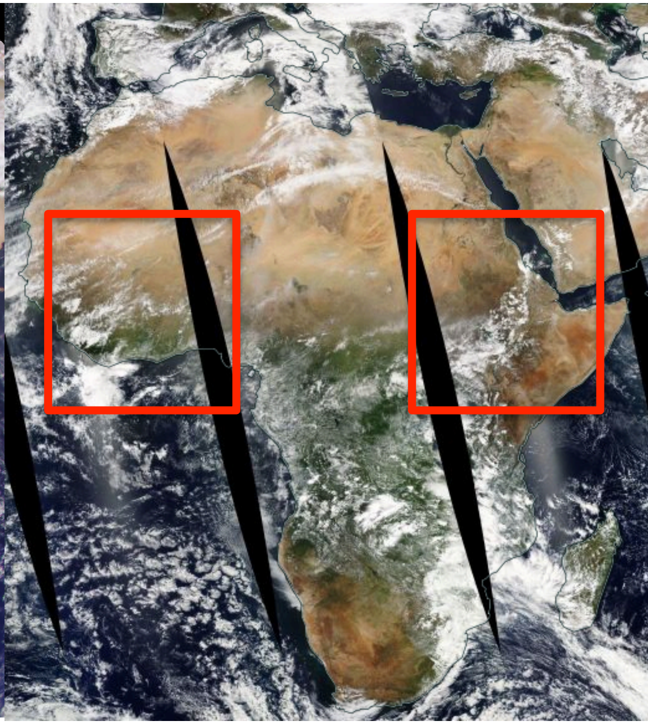
MODIS/Terra&Aqua and EPIC/DSCOVR



MODIS Terra
10:30 equatorial crossing time

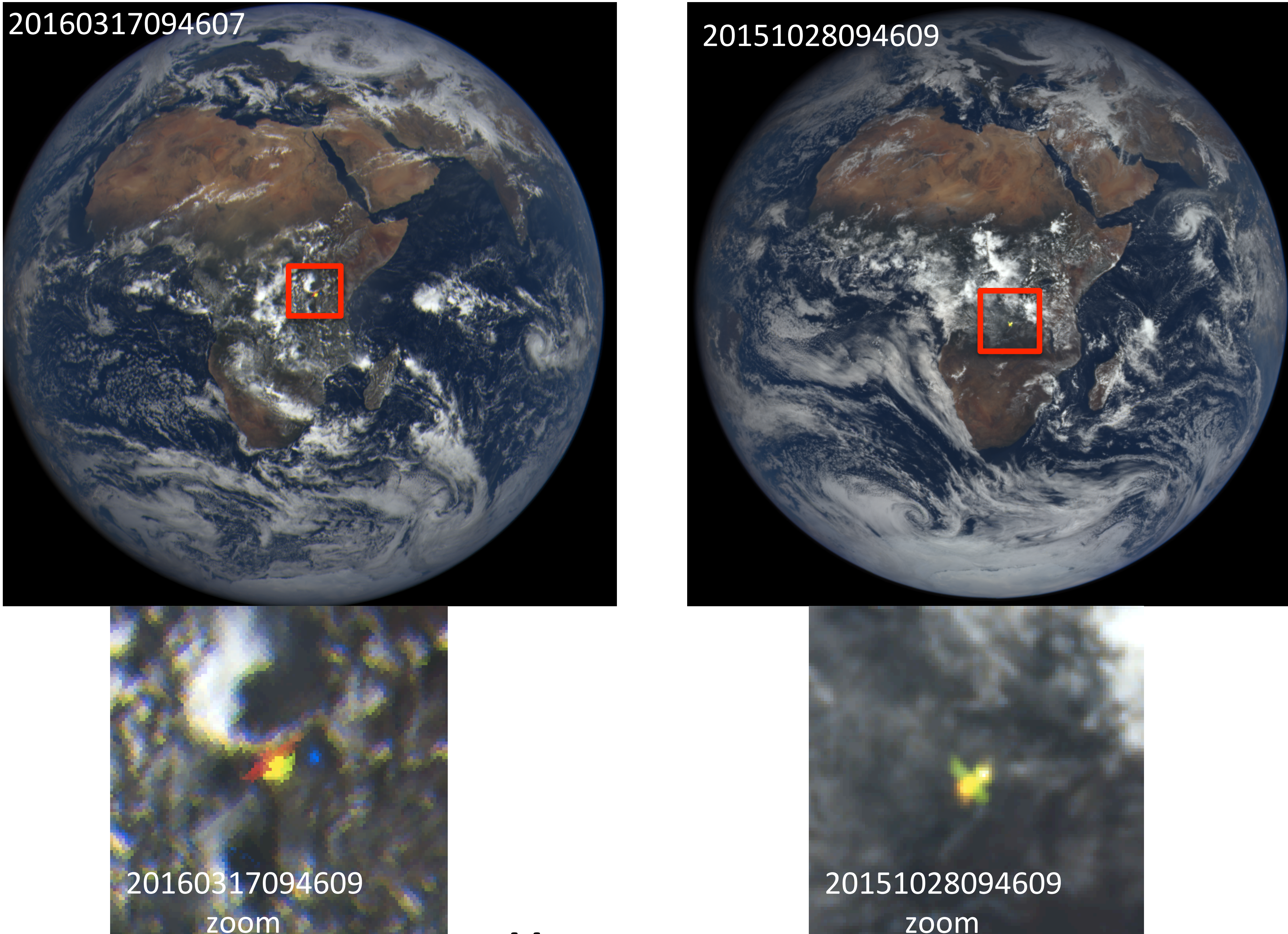


EPIC
10:56 UTC



MODIS Aqua
13:30 equatorial crossing time

Examples of bright flashes

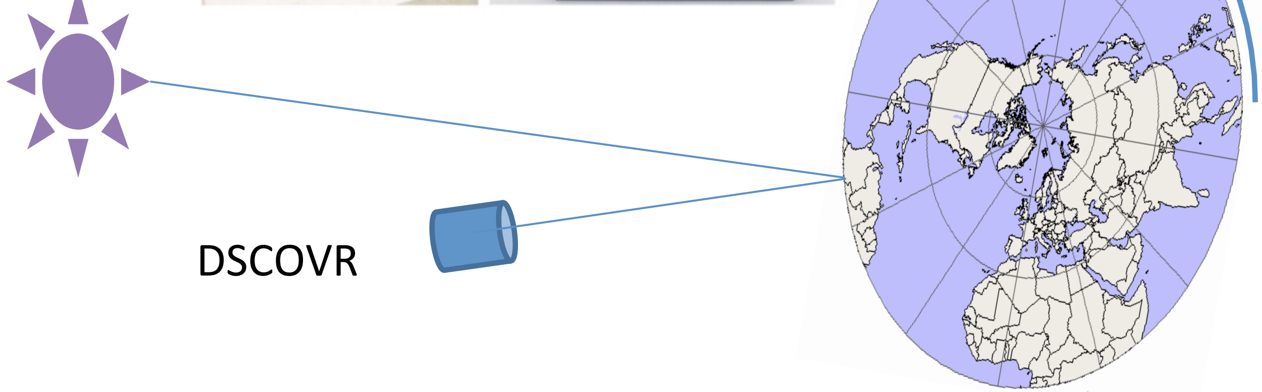


https://epic.gsfc.nasa.gov

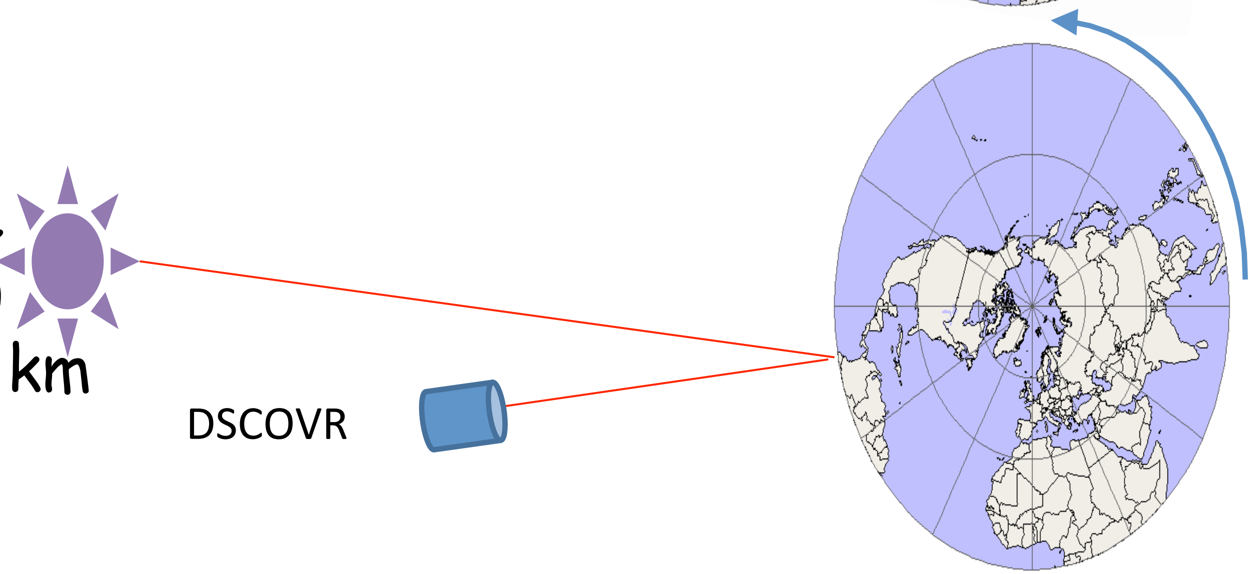
Flashes are colorful because of Earth rotation

The EPIC filter wheel

Time of blue image

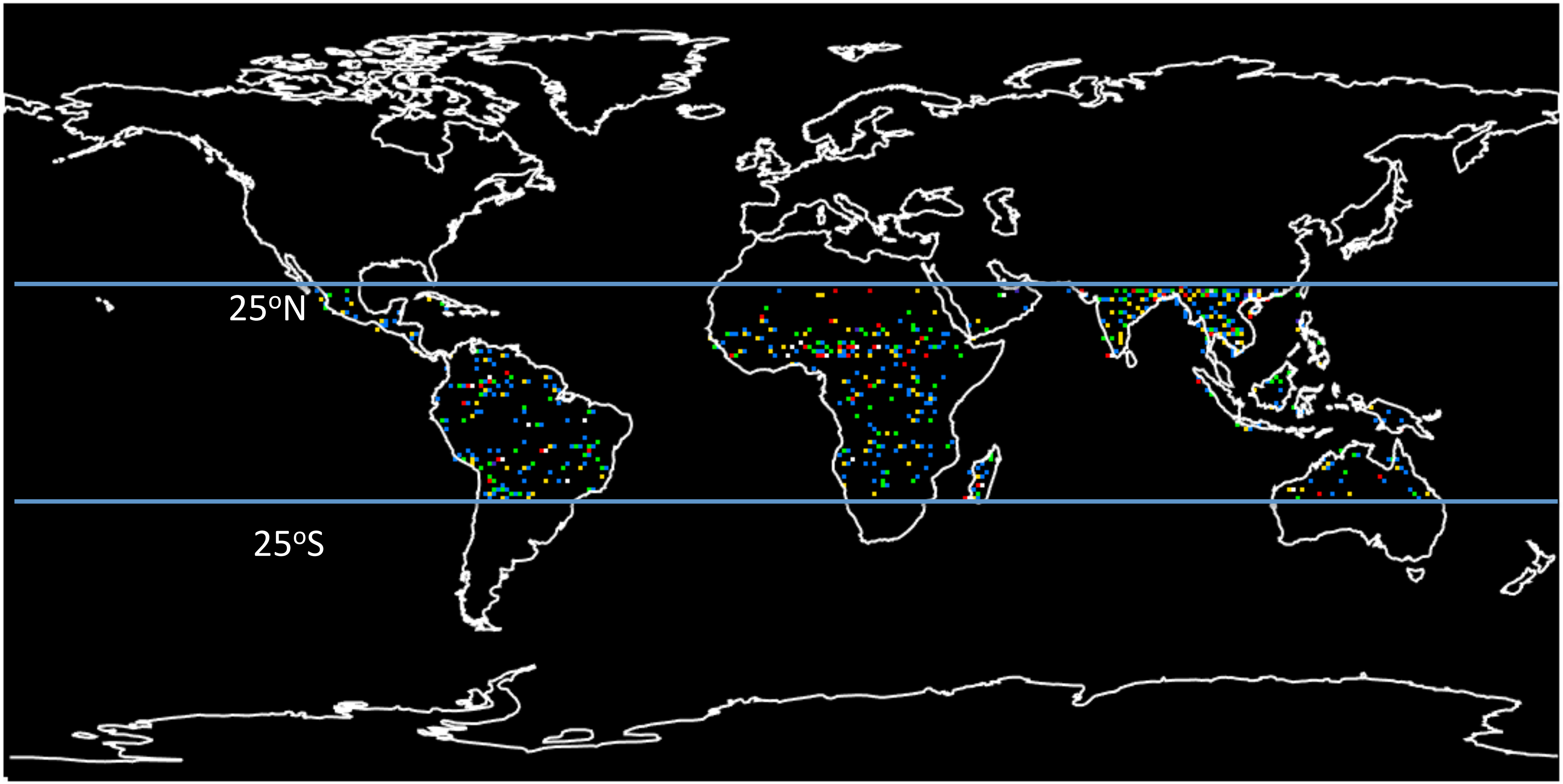


Time of red image
(≈4 minutes later)
Glint shifts by ≈ 100 km

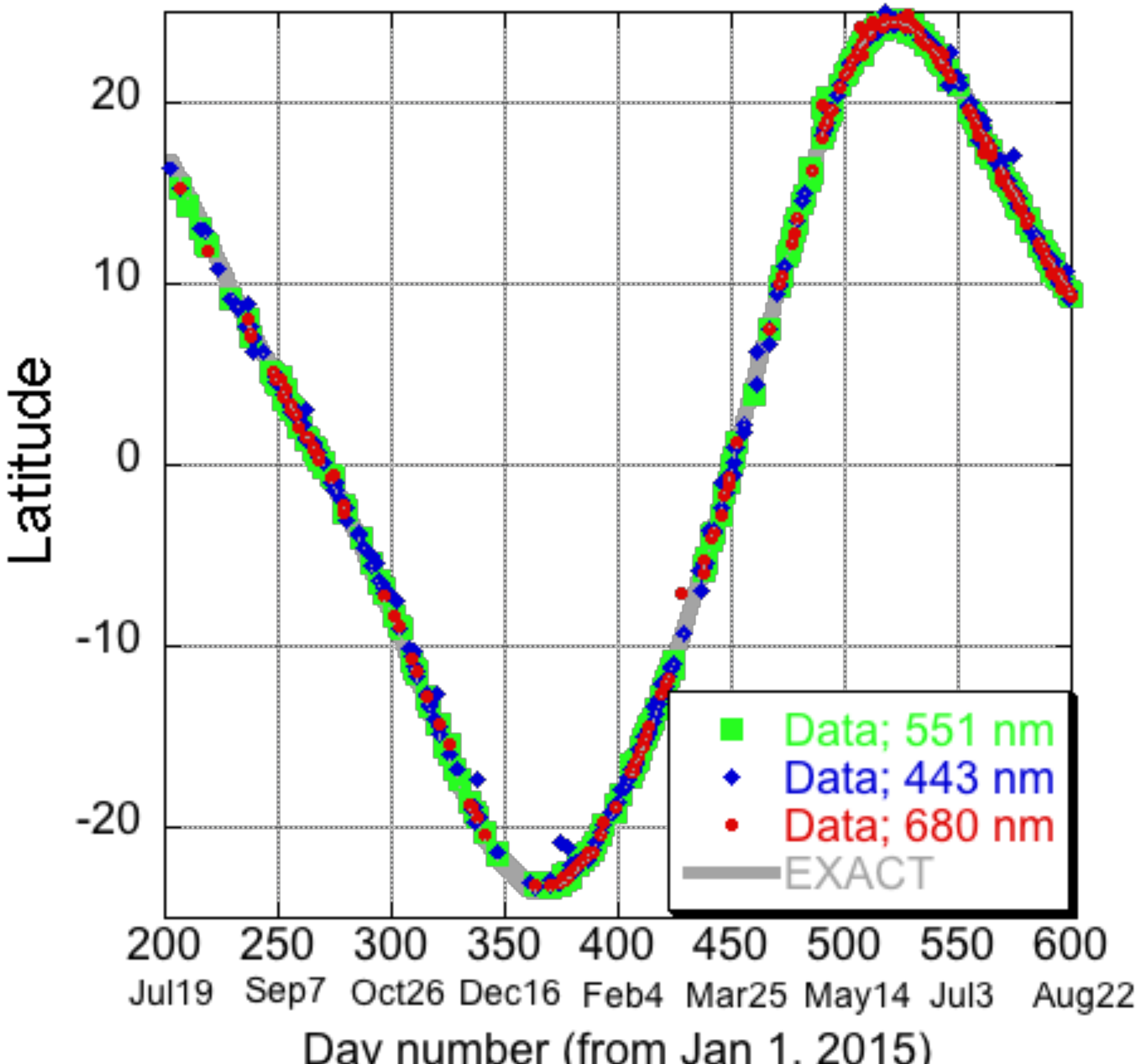


Locations

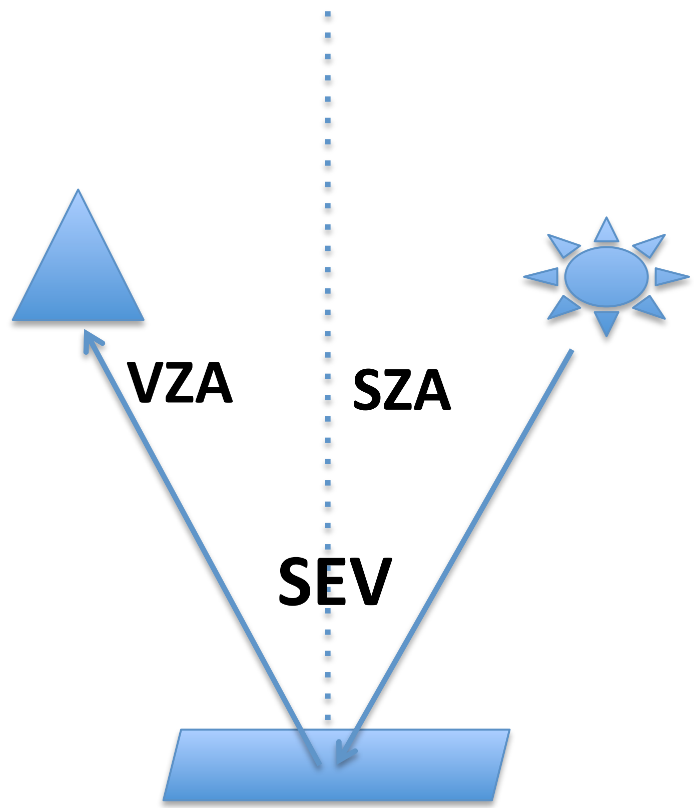
Location of flashes over a year



Latitude and Longitude

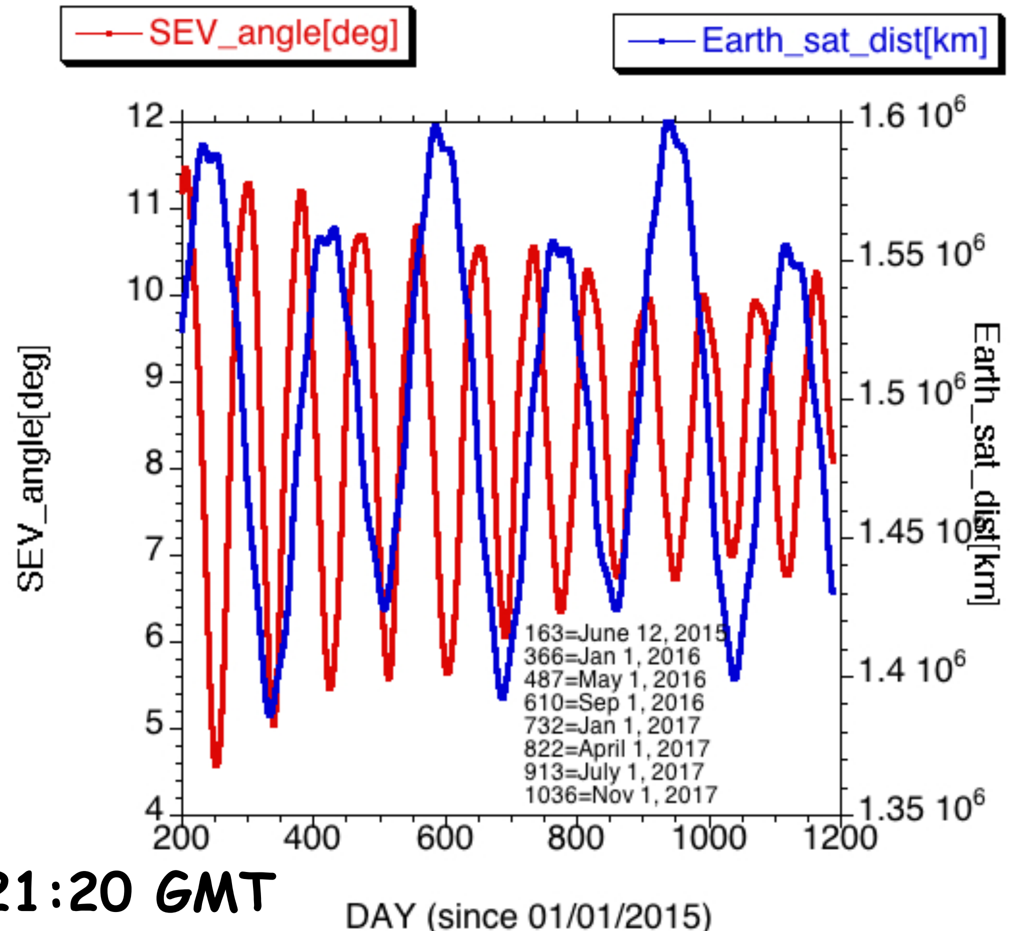


Direction



SEV = Solar Earth Vehicle (angle)
SZA = Solar Zenith Angle
VZA = Viewing (vehicle) Zenith Angle

SEV = Solar Earth Vehicle (Angle)



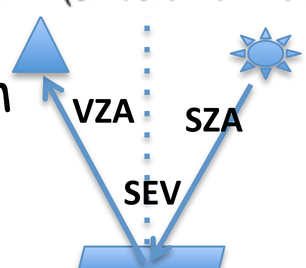
27 Sep. 2017 21:20 GMT

1001.9 day since 01/01/2015

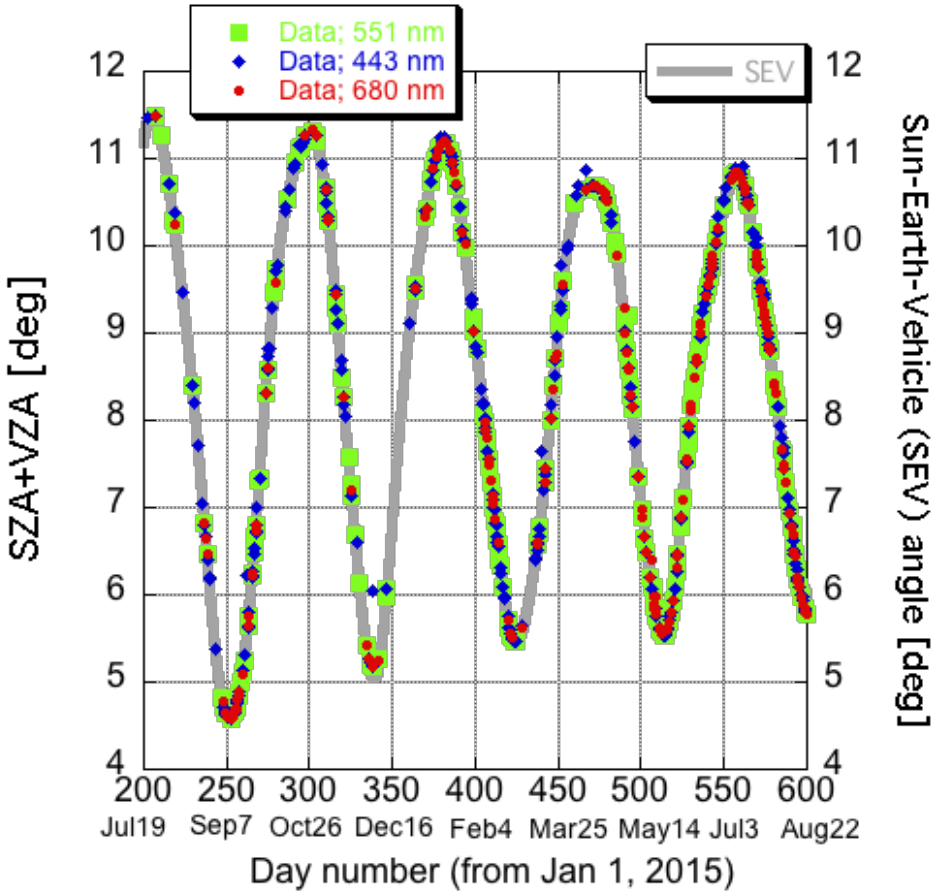
dist. from Earth = 1.477 10^6 km

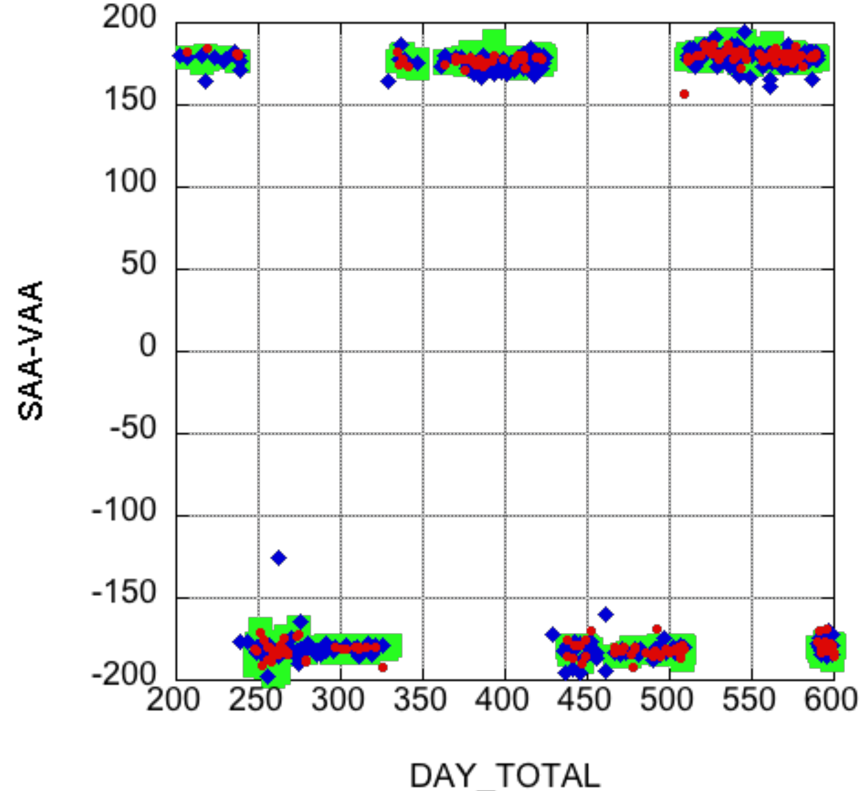
SEV = 9.63°

Velocity = 0.333 km/sec

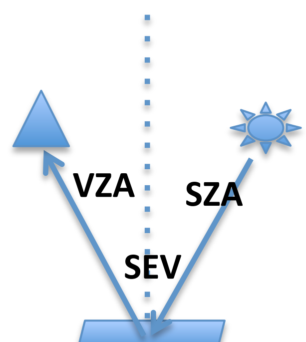


Angles





SZA + VZA = SEV

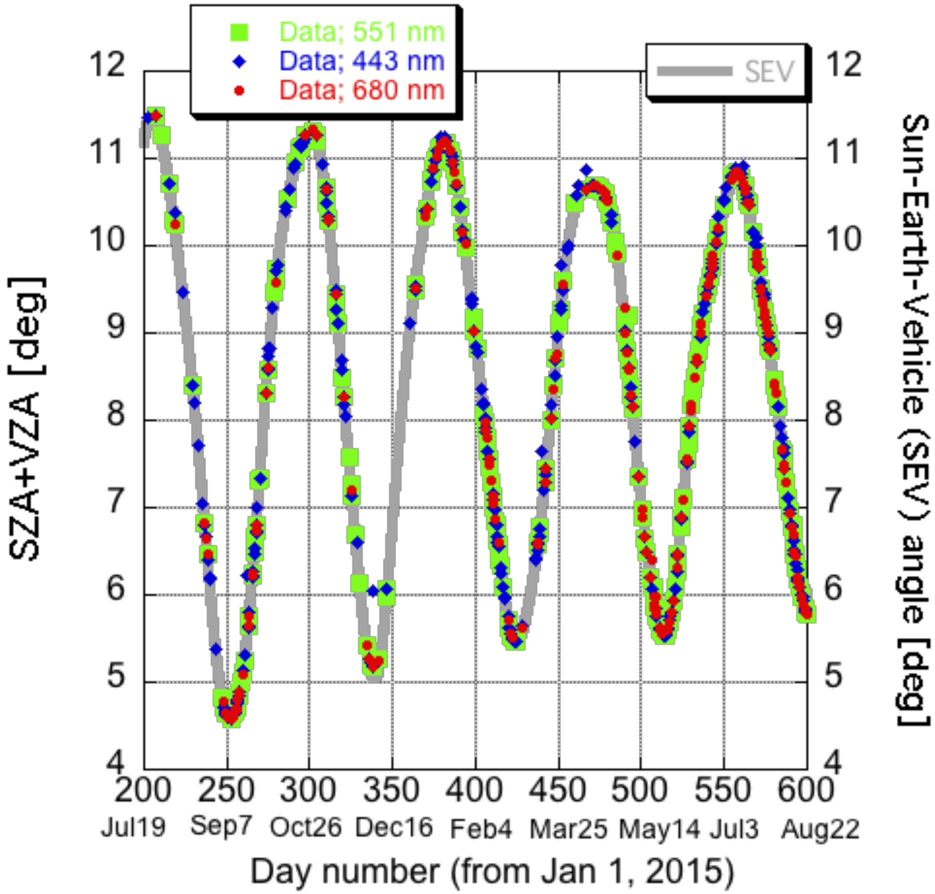


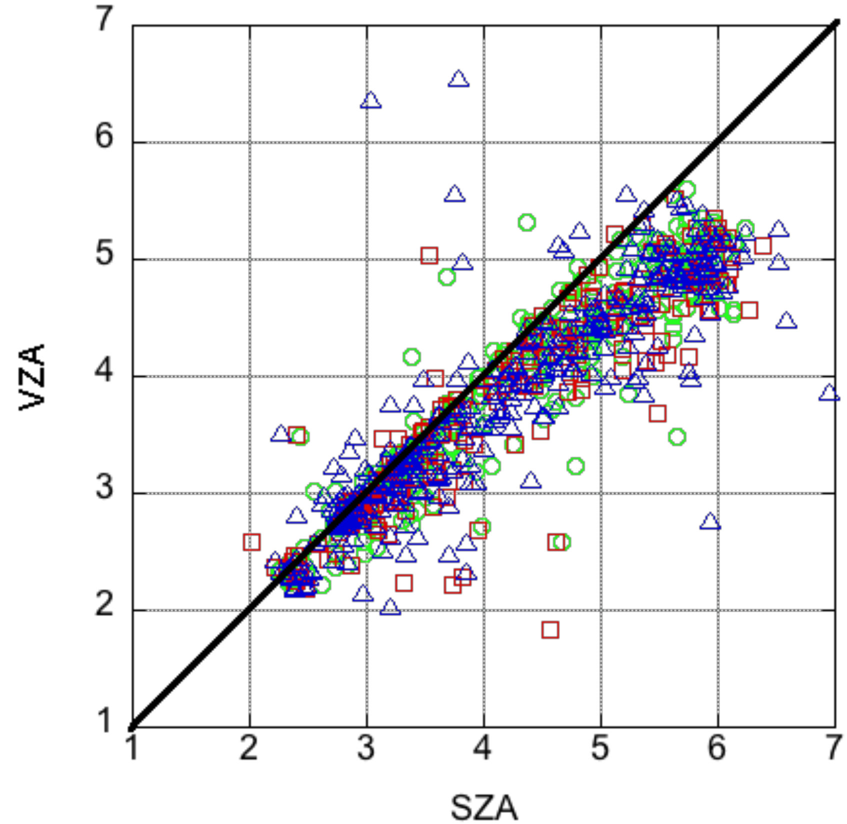
SAA = VAA ± 180

SZA = solar zenith angle
VZA = viewing (or vehicle) zenith angle

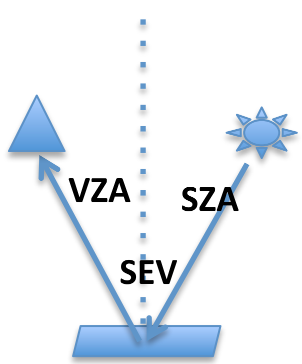
SAA = solar azimuth angle
VAA = viewing azimuth angle

Angles





SZA + VZA = SEV

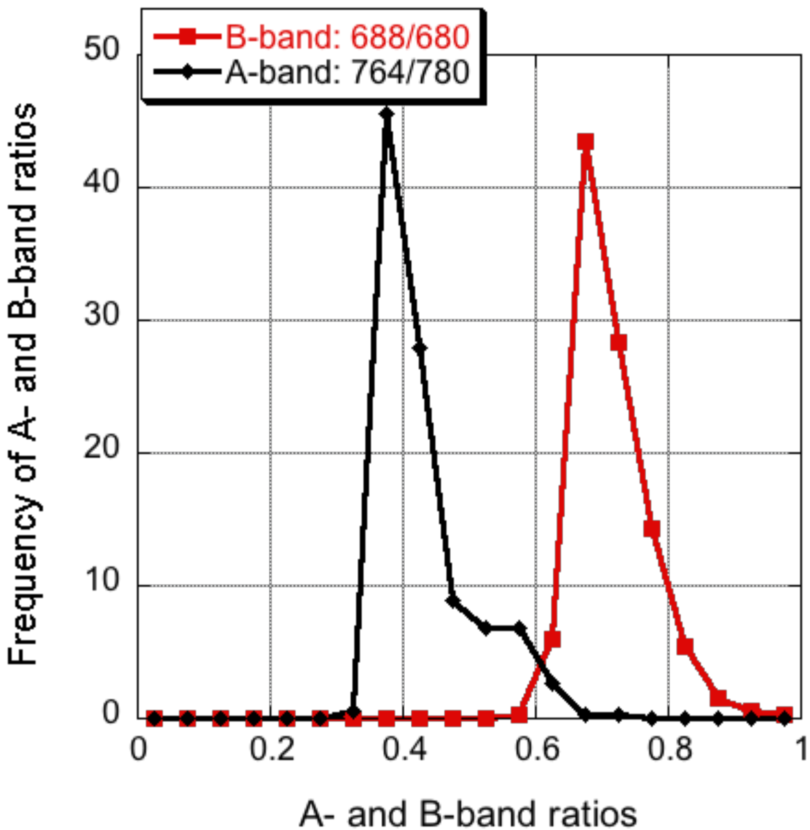


SZA = solar zenith angle
VZA = viewing (or vehicle) zenith angle

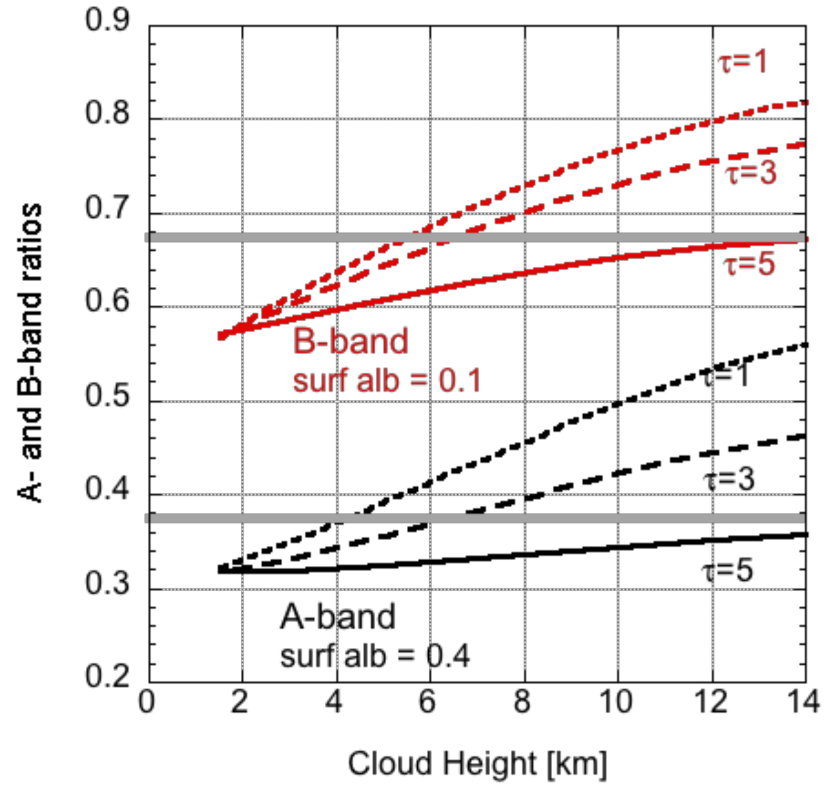
Height

Height of the detected sunglints

Observations



RT calculations



As was detected by POLDER (Breon&Dubrulle, 2004), the clouds that are higher than 5.5 km (~500 hPa) have less horiz. oriented plates than clouds between 500 and 700 hPa. This is consistent with the CALIPSO results (Noel&Chepfer, 2010): the presence of the horiz. oriented crystals is most frequent between -30°C and -10°C and they are almost nonexistent in ice clouds colder than -30°C.

Particle Size

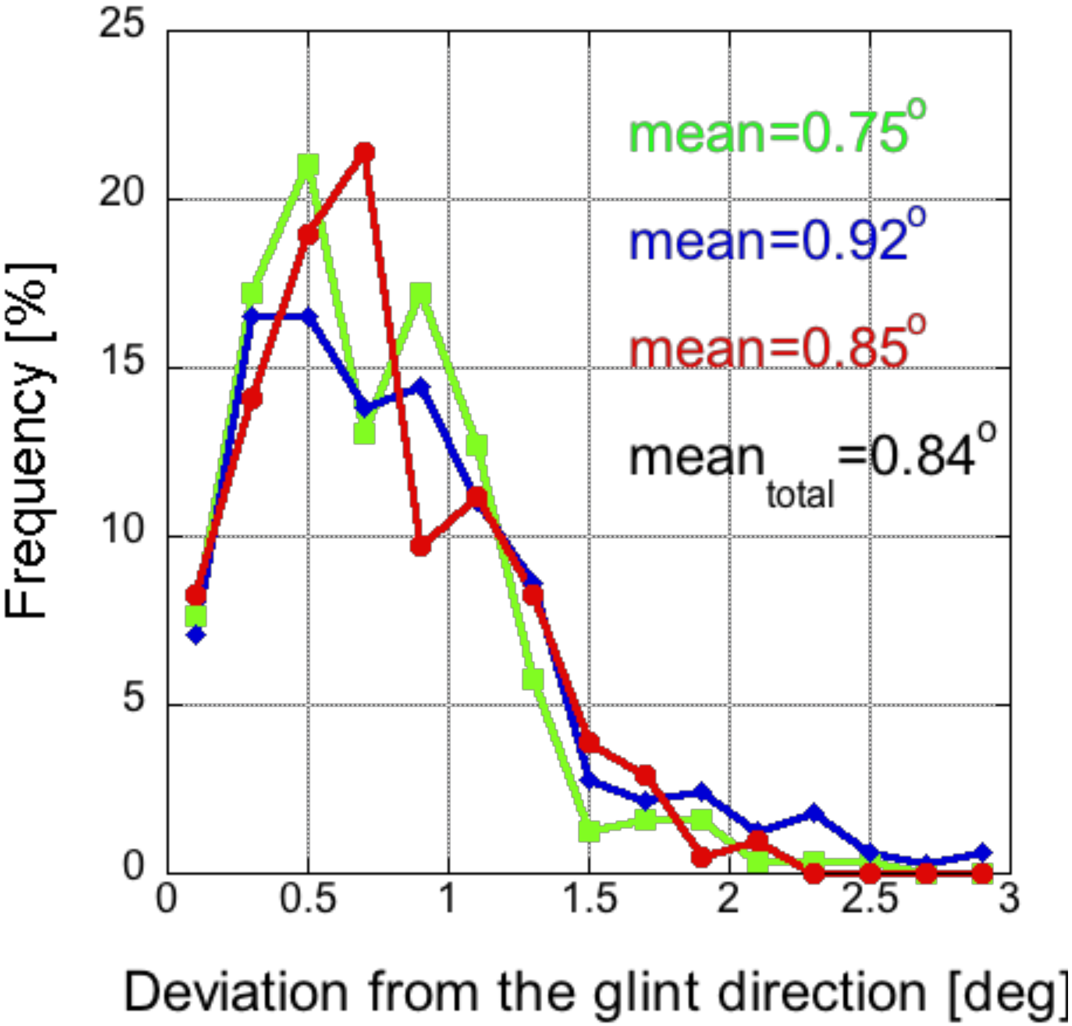
Tiny hexagonal platelets of ice, floating in air in nearly perfect horizontal alignment are likely responsible for the glints observed by EPIC over land.

What could be a crystal size?

The specular signal within an angle of only ~3×10^{-4} degree ($0.62^{\circ}/2048$) must either contain **smooth large oriented ice plates** or **smaller oriented platelets sending back diffracted light**.

Size distribution of such crystals depends greatly on cloud temperature and humidity but the range is from **tens of µm to mm**.

Tilt angle = Deviation from the direction of specular refl.



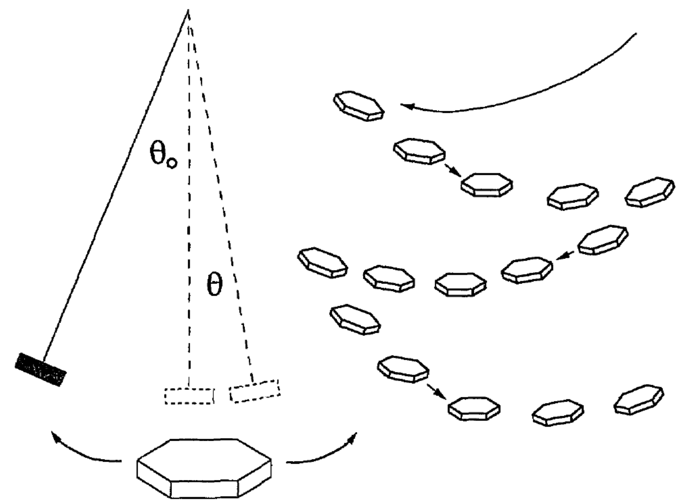


Fig. 8. Pendulum motion of a plate crystal.

20 July 1994 / Vol. 33, No. 21 / APPLIED OPTICS 4583

from Lynch, 1994

~80% of all cases have the deviation angle < 1° while ~96-99% cases < 2°.

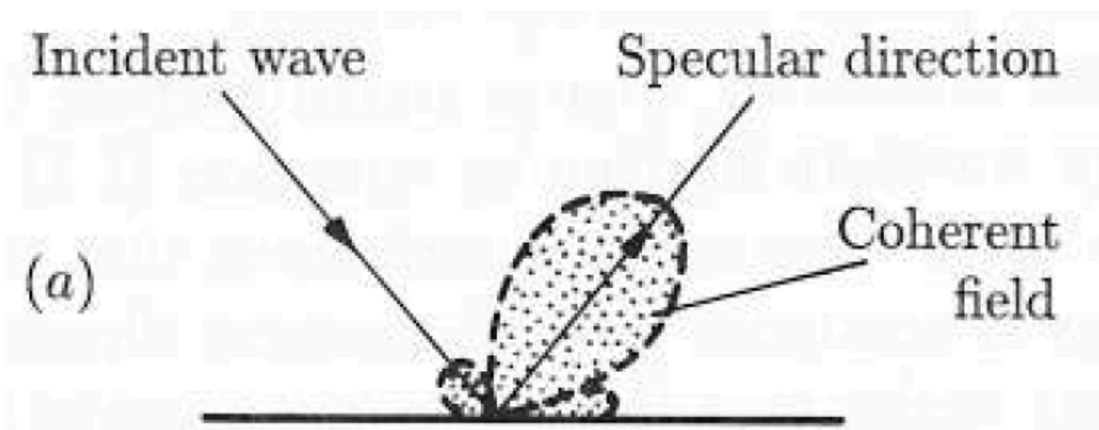
The aerodynamic model predicts that a typical tilt angle varies "*between 0.5° and a few degrees from weak to strong turbulence.*" The model indicates that the hor. plate diam. is between **100 μm** and a **few mm** (Breon & Durbulle, 2004)

Effect of diffraction

$$\Theta = \lambda/D \Rightarrow D = \lambda/\Theta$$

Θ is the angular res., λ is the wavelength and D is the diameter of ice platelet;

If λ=0.5 μm and D=50 μm, then $\Theta=10^{-2}$ (or on the order of 1^{o})
Θ is angular half-width of the diffraction lobe around the specular dir.



from Crawford, 1968 p. 486

The angular spread of about 1^{o} can also be explained by the simple diffraction estimate.

Take home message

- Many DSCOVR/EPIC images contain unexpected bright flashes of light over land;

- A yearlong time series of flash latitudes, scattering angles and O2 absorption demonstrates that these flashes are specular reflections off tiny ice platelets, floating in air nearly horizontally;

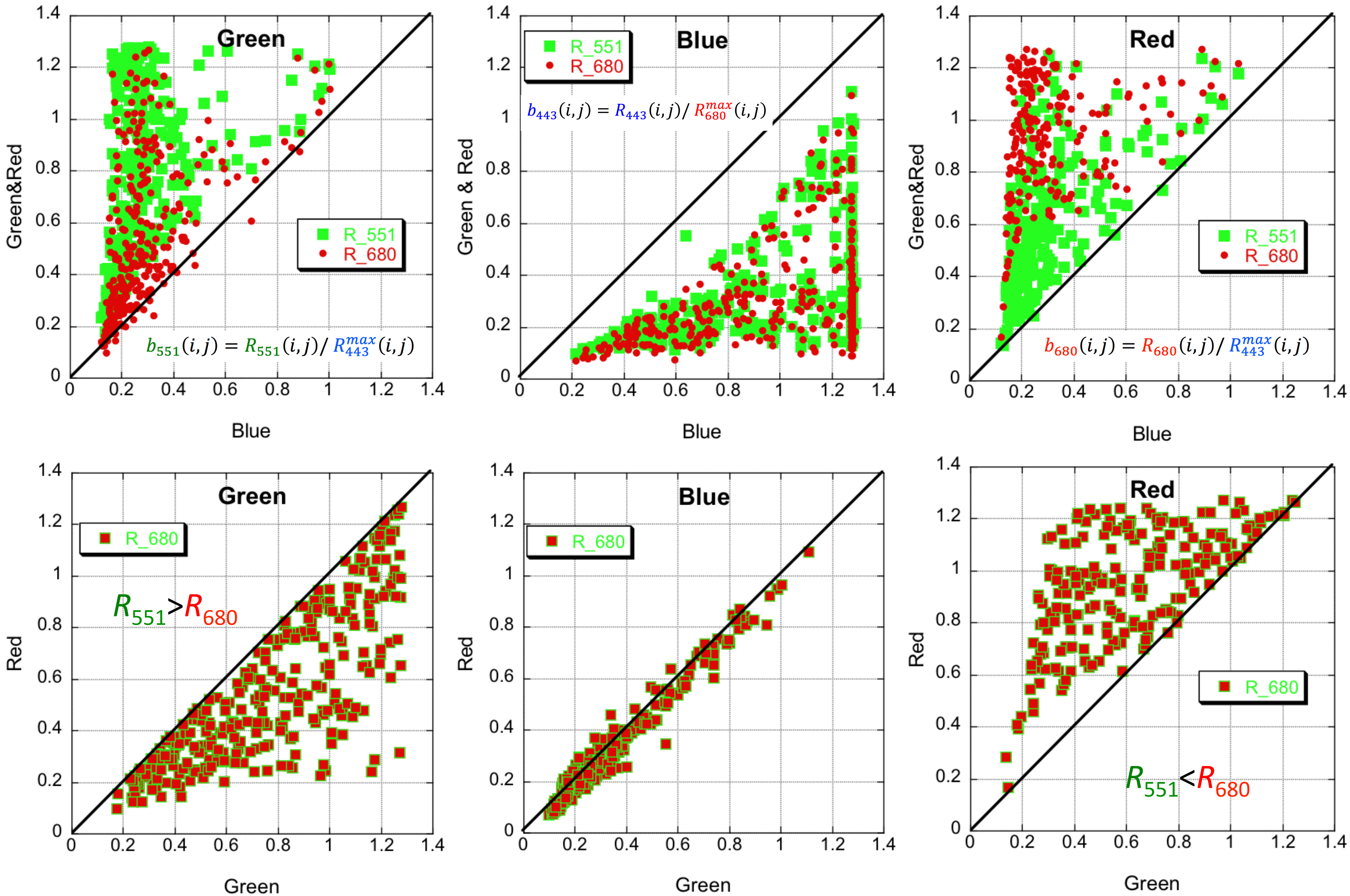
- Such deep space detection of tropospheric ice can be used to constrain the likelihood of oriented crystals and their contribution to Earth albedo;

- These glint observations can lead to new ideas of detecting starlight glints off faint companions in our search for habitable exoplanets.

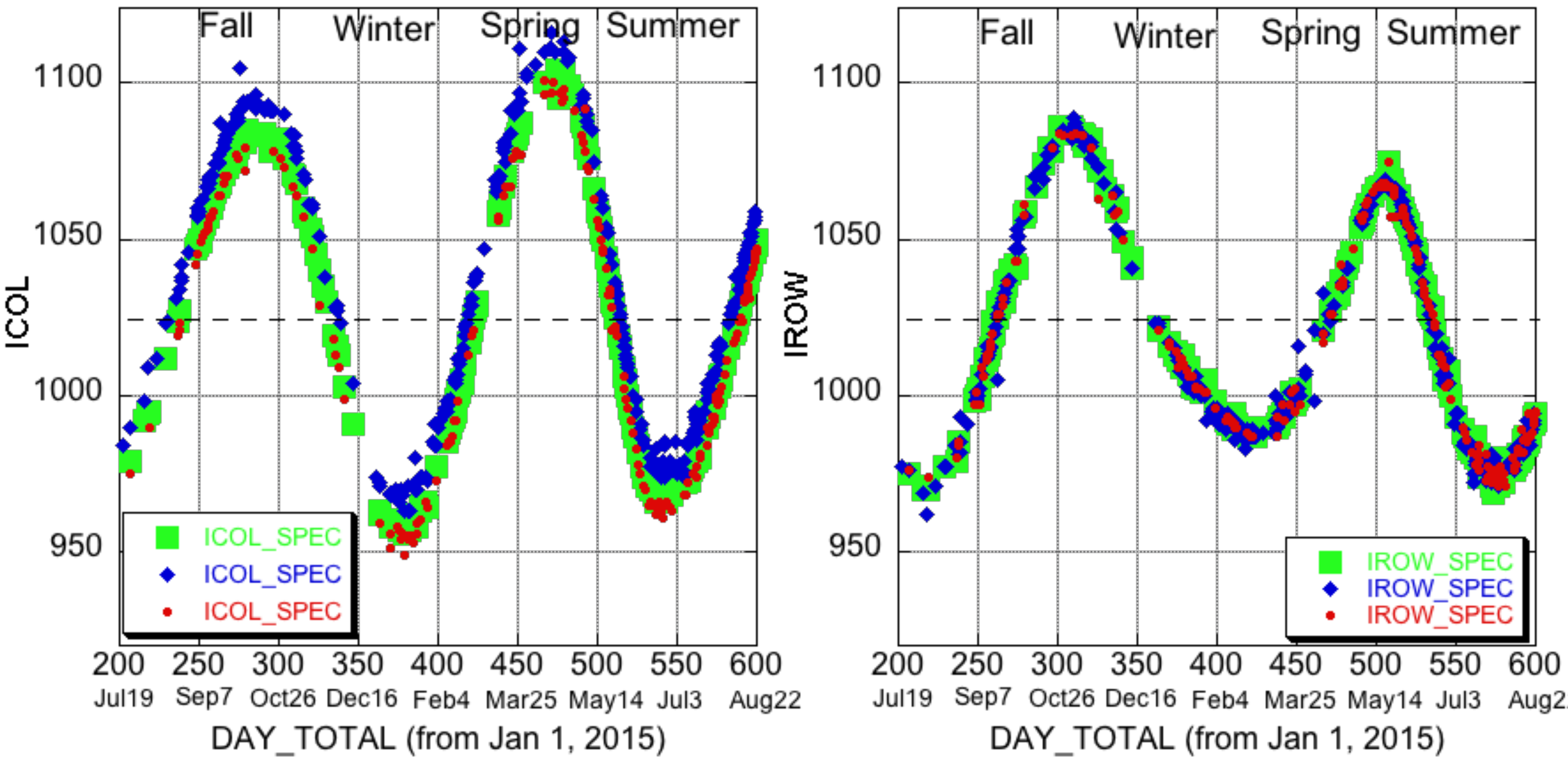
Carl Sagan et al. (Nature, 1993) used the spacecraft Galileo flyby observation of Earth as a control experiment in search for life elsewhere. Based solely on observations of specular reflection, they deduced that the Earth, was covered in part by liquid water oceans and that the biota, should it exist, must be water-based.

Thank you !

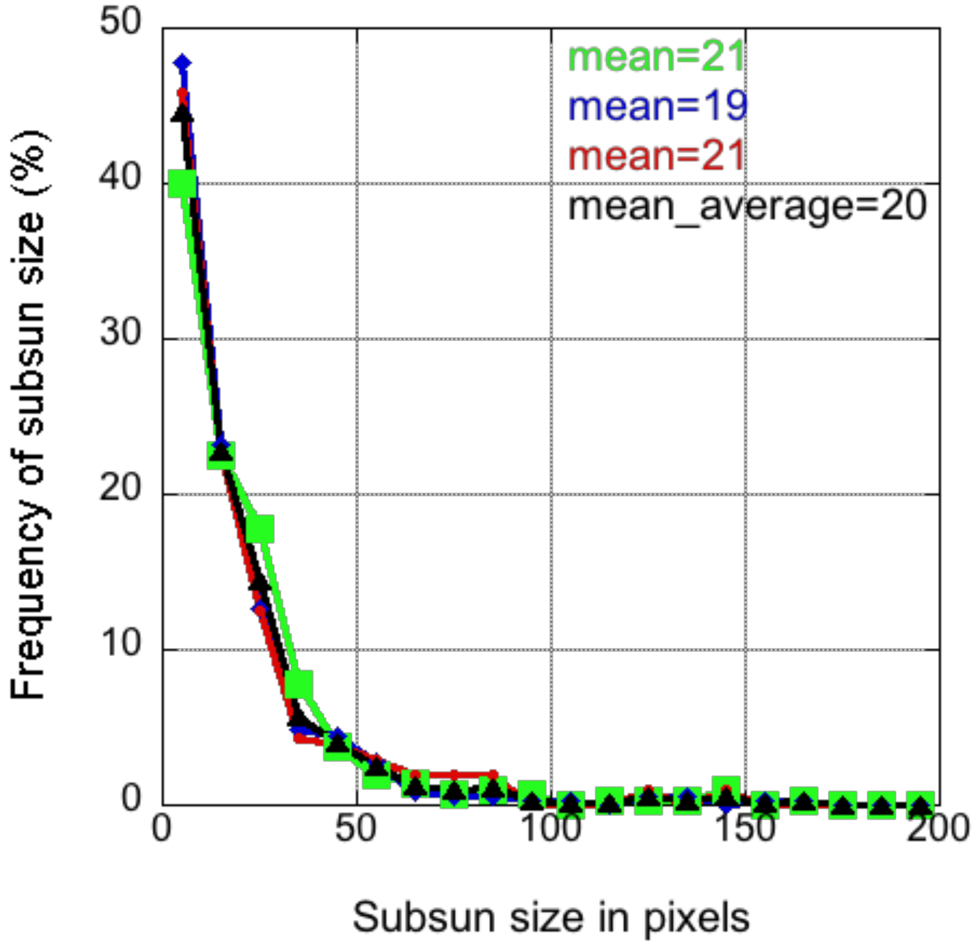
Reflectance values for the detected green, blue and red subsuns



Location in CCD

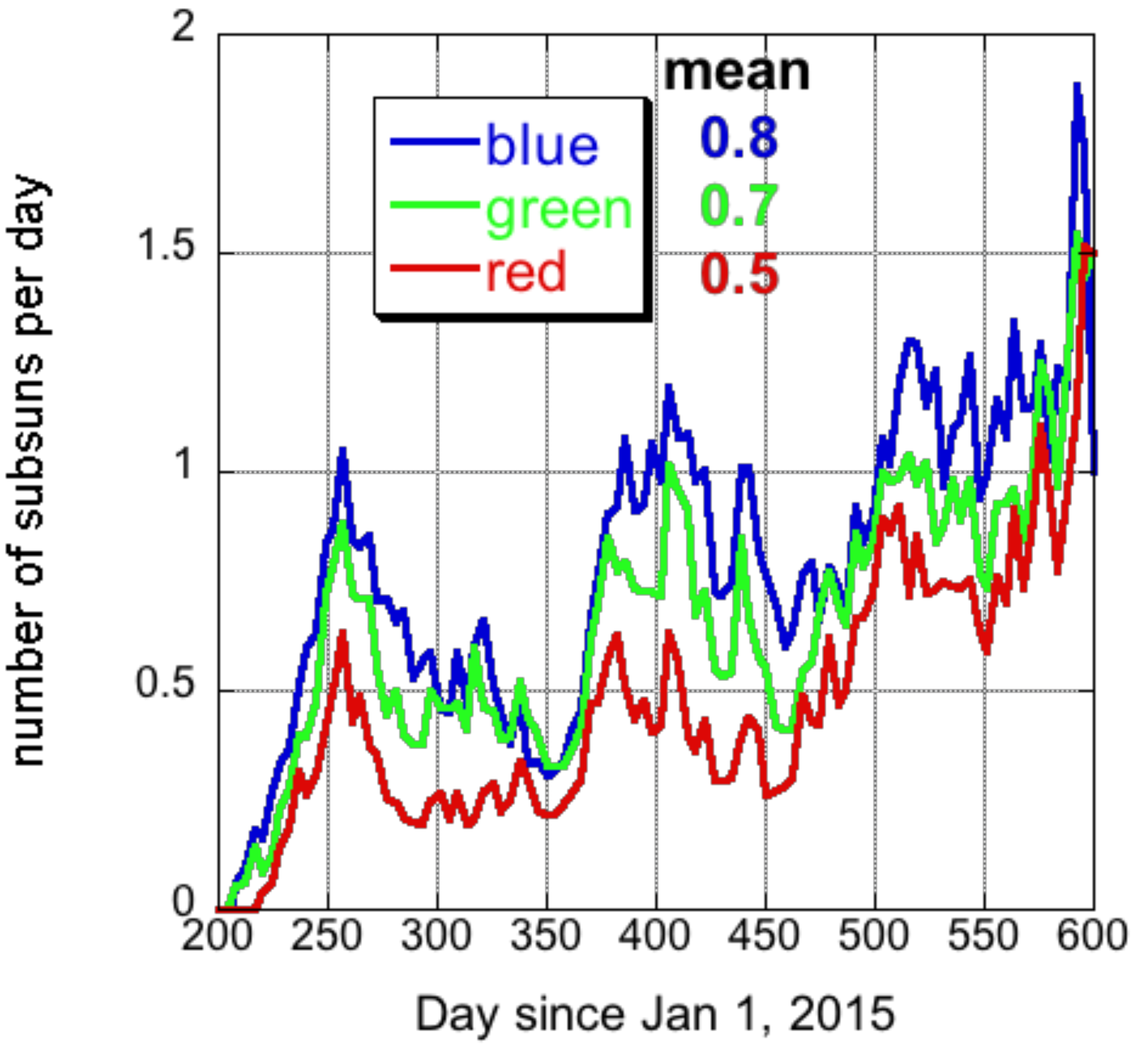


Size of the subsuns



The mean value is ~20 or ~4-5 pixels on each side. 9% of all subsuns consists of only 1 pixel, 45% have <10 pixels while 97% have <80 pixels, which is ~1^{o} in the range of deviation from the direction of specular reflection of the horizontally oriented crystals.

Number of detected subsuns per day



The averaged number of images per day is ~15; thus the frequency of detecting a subsun per image is ~5%

Deviation from exact glint angle

Tilt

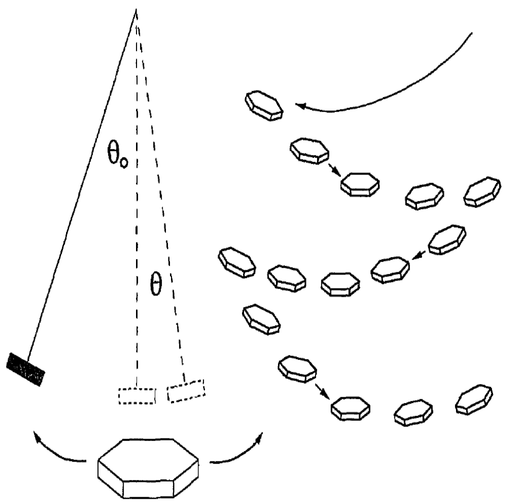


Fig. 8. Pendulum motion of a plate crystal.

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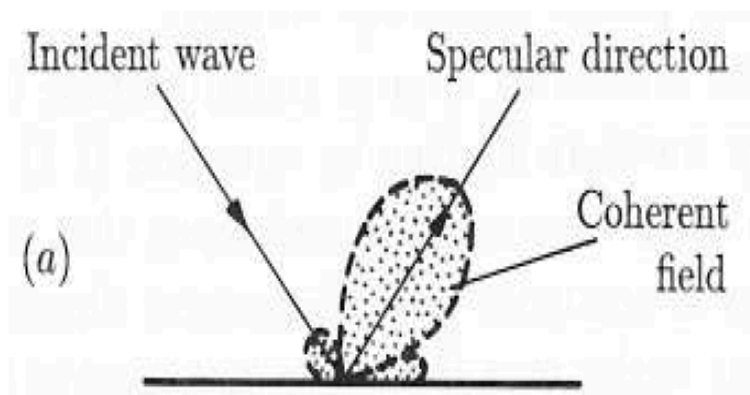
from Lynch (1994, Appl. Optics)

Katz (1996, JAS): tilt depends on Reynolds number

Bréon & Durbulle (2004, JAS): tilt angle varies "*between 0.5º and a few degrees from weak to strong turbulence*" for plate diameters between 100 µm and a few mm

Diffraction



$$\Theta = \lambda / D$$

Θ is half-width of the diffraction lobe
For λ = 0.5 µm and D = 50 µm, $\Theta = 10^{-2}$ (≈ 0.6º)

Solar disc

Diameter is 0.5°

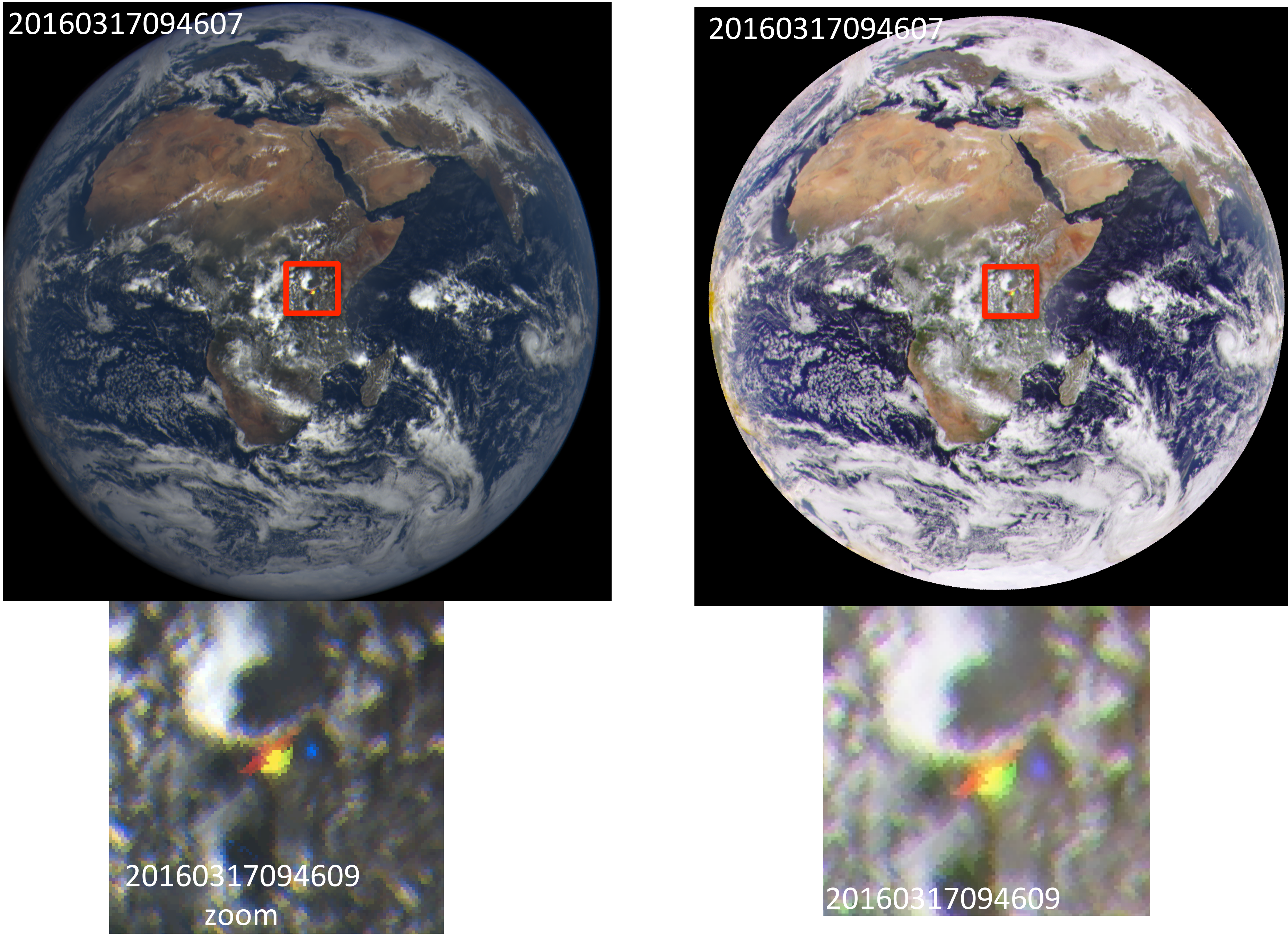
Frequency of horizontally oriented crystals

Based on

(i) # of detected subsuns as a function of deviation from a sunglint dir.;
(ii) average size of a subsun;
(iii) # of subsuns per day and per image;
(iv) fraction of over land pixels between 25S and 25N;
(v) fraction of ice clouds;

we estimated the frequency of horizontally oriented ice crystals as ~5-6%

If crystals are horizontally oriented, there is a very strong specular reflection which increases cloud albedo by ~30% compared to randomly oriented crystals [Takano&Liou, 1989].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